

A Measurement of the Induced polarization of electro-produced $\Lambda(1116)$ with CLAS

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HUGS 2008



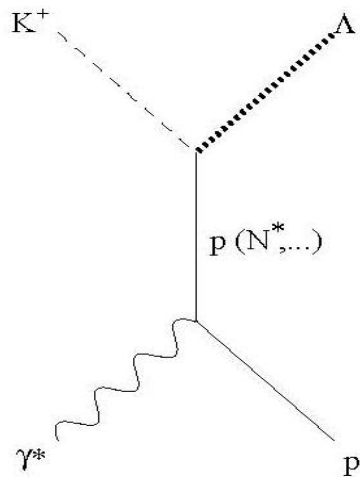
- Why study electromagnetic production of kaons?
- Formalism.
- Polarization observables.
- CLAS detector and capabilities.
- Analysis
- Summary and future work.

Electromagnetic Production of Kaons

$$e + p \rightarrow e' + K^+ + (\Lambda \rightarrow \pi + p)$$

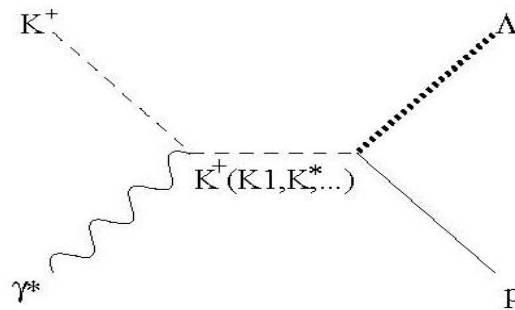
$$\gamma^* p \rightarrow K^+ Y$$

s-channel



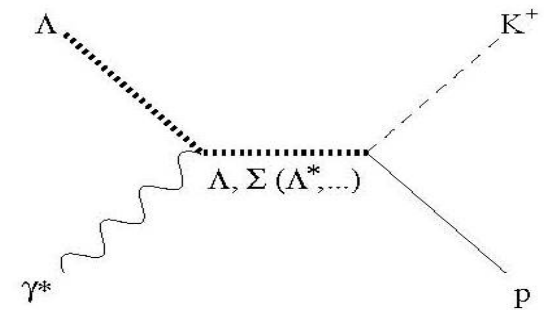
Nucleon resonances:
“Missing” baryon searches

t-channel



Meson exchange

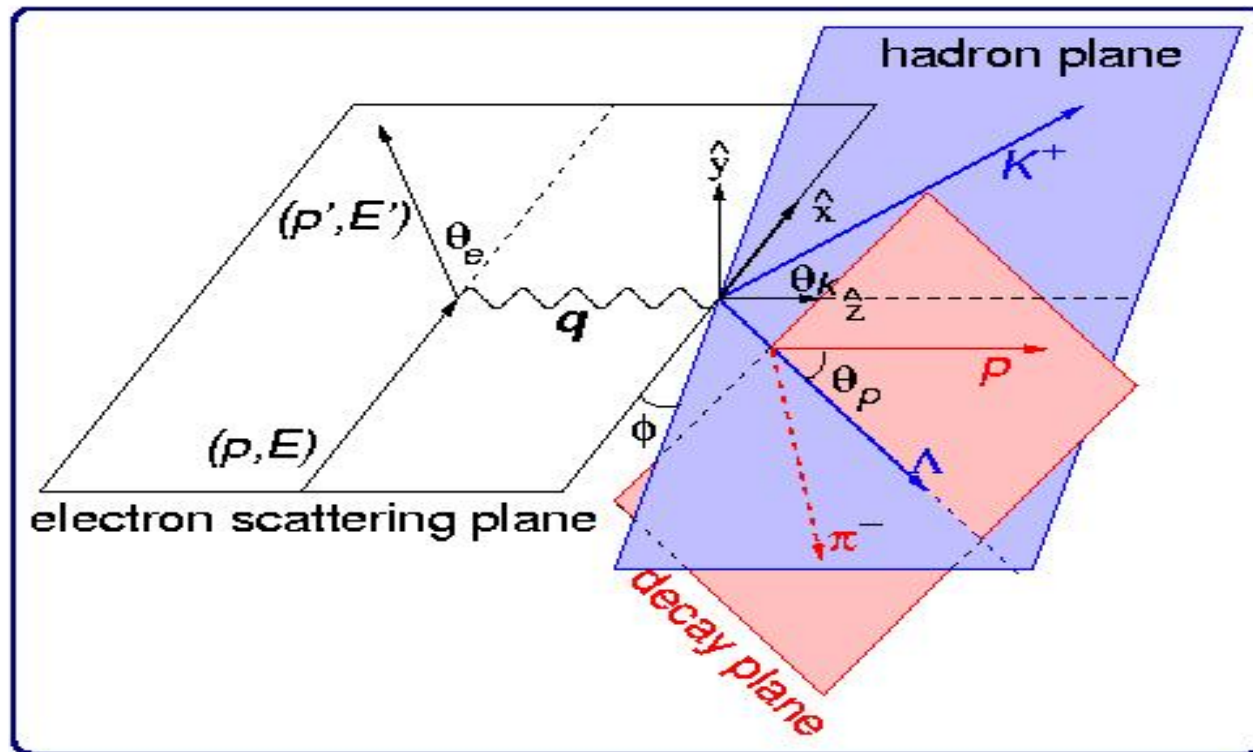
u-channel



Hyperon resonances



Kinematics Definitions



$\nu = E - E'$ Energy transferred by virtual photon.

$Q^2 = -q^2 = 4EE' \sin^2(\theta_e/2)$ Momentum of virtual photon.

$W = M_p + 2M_p \nu - Q^2$ C.M. mass of intermediate state.

Cross Section for Electroproduction

$$\boxed{\frac{d^3\sigma}{dE' d\Omega_e d\Omega_K^*} = \Gamma \frac{d\sigma_\nu}{d\Omega_K^*}}$$

Polarized beam, target & recoil hyperon

$$\begin{aligned} \frac{d\sigma_\nu}{d\Omega_K^*} = & K_f \sum_{\alpha,\beta} S_\alpha S_\beta \left[R_T^{\beta\alpha} + \epsilon_L R_L^{\beta\alpha} + \sqrt{2\epsilon_L(1+\epsilon)} ({}^cR_{LT}^{\beta\alpha} \cos \Phi + {}^sR_{LT}^{\beta\alpha} \sin \Phi) \right. \\ & + \epsilon ({}^cR_{TT}^{\beta\alpha} \cos 2\Phi + {}^sR_{TT}^{\beta\alpha} \sin 2\Phi) \\ & \left. + h \sqrt{2\epsilon_L(1-\epsilon)} ({}^cR_{LT'}^{\beta\alpha} \cos \Phi + {}^sR_{LT'}^{\beta\alpha} \sin \Phi) + h \sqrt{1-\epsilon^2} R_{TT'}^{\beta\alpha} \right]. \end{aligned}$$

$$S_\alpha = (1, \hat{S}_x, \hat{S}_y, \hat{S}_z) \quad S_\beta = (1, \hat{S}_{x'}, \hat{S}_{y'}, \hat{S}_{z'})$$

Study kinematic dependence of observables over a broad range of W , Q^2 , and $\cos\theta_K^*$.



Cross Section for Electroproduction

$$\boxed{\frac{d^5\sigma}{dE' d\Omega_e d\Omega_K^*} = \Gamma \frac{d^2\sigma_\nu}{d\Omega_K^*}}$$

Unpolarized beam/target/recoil

$$\sigma_0 \equiv \left(\frac{d\sigma_\nu}{d\Omega_K^*} \right)^{00} = K_f \left[R_T^{00} + \epsilon_L R_L^{00} + \sqrt{2\epsilon_L(1+\epsilon)} R_{LT}^{00} \cos \Phi + \epsilon R_{TT}^{00} \cos 2\Phi \right]$$

σ_u

$$\Gamma = \frac{\alpha}{8\pi^2} \frac{W}{M_p^2 E^2} (W^2 - M_p^2) \left[\frac{1}{Q^2(1-\epsilon)} \right]$$

$$\epsilon = \frac{1}{1 + \frac{2\mathbf{q}^2}{Q^2} \tan^2 \frac{\theta_e}{2}}, \quad \epsilon_L = \frac{Q^2}{\nu^2} \epsilon.$$



Cross Section for Electroproduction

Polarized beam & recoil hyperon, unpolarized target.

$$\frac{d\sigma_v}{d\Omega_K^*} = \sigma_0(1 + hA_{LT'} + P_{x'}\hat{x}' \cdot \hat{S}' + P_{y'}\hat{y}' \cdot \hat{S}' + P_{z'}\hat{z}' \cdot \hat{S}')$$

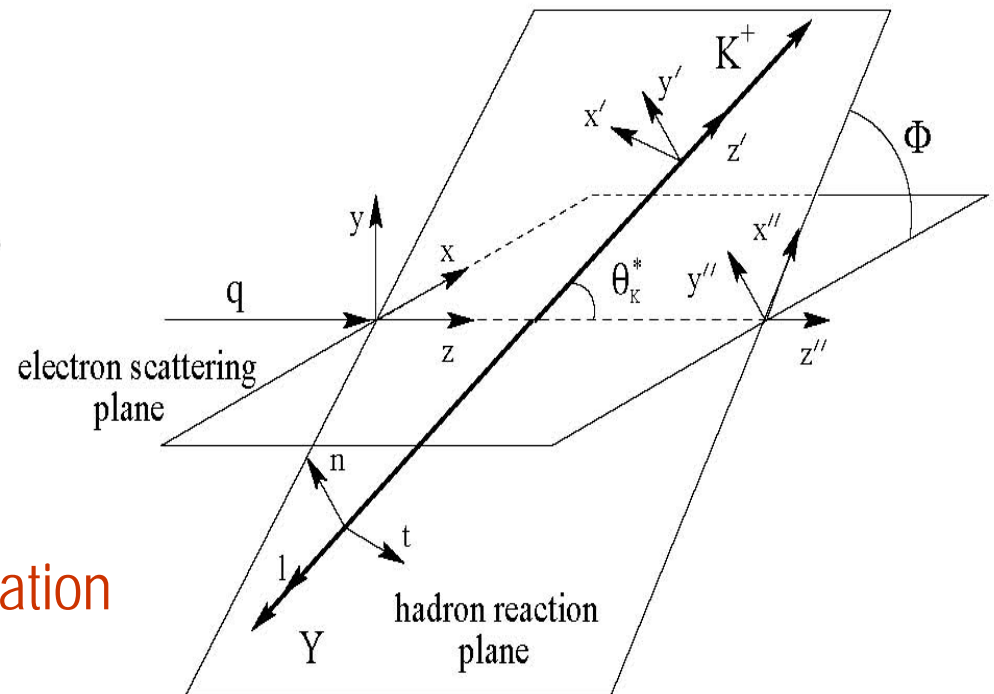
Where:

$$A_{LT'} = \frac{K_f}{\sigma_0} \sqrt{2\epsilon_L(1 - \epsilon)} R_{LT'}^{00} \sin \Phi$$

$$P_{i'} = P_{i'}^0 + hP_{i'}'$$

Induced polarization

Transferred polarization



Polarization Observables in (x', y', z')

Induced polarization

$$P_{x'}^0 = \frac{K_f}{\sigma_0} \left(\sqrt{2\epsilon_L(1+\epsilon)} R_{LT}^{x'0} \sin \Phi + \epsilon R_{TT}^{x'0} \sin 2\Phi \right)$$

$$P_{y'}^0 = \frac{K_f}{\sigma_0} \left(R_T^{y'0} + \epsilon_L R_L^{y'0} + \sqrt{2\epsilon_L(1+\epsilon)} R_{LT}^{y'0} \cos \Phi + \epsilon R_{TT}^{y'0} \cos 2\Phi \right)$$

$$P_{z'}^0 = \frac{K_f}{\sigma_0} \left(\sqrt{2\epsilon_L(1+\epsilon)} R_{LT}^{z'0} \sin \Phi + \epsilon R_{TT}^{z'0} \sin 2\Phi \right),$$

Transferred polarization

$$P_{x'}' = \frac{K_f}{\sigma_0} \left(\sqrt{2\epsilon_L(1-\epsilon)} R_{LT'}^{x'0} \cos \Phi + \sqrt{1-\epsilon^2} R_{TT'}^{x'0} \right)$$

$$P_{y'}' = \frac{K_f}{\sigma_0} \sqrt{2\epsilon_L(1-\epsilon)} R_{LT'}^{y'0} \sin \Phi$$

$$P_{z'}' = \frac{K_f}{\sigma_0} \left(\sqrt{2\epsilon_L(1-\epsilon)} R_{LT'}^{z'0} \cos \Phi + \sqrt{1-\epsilon^2} R_{TT'}^{z'0} \right).$$

Integrated Polarization Observables

$\mathcal{P}_{x'}^0$	0
$\mathcal{P}_{y'}^0$	$K_I(R_T^{y'0} + \epsilon_L R_L^{y'0})$
$\mathcal{P}_{z'}^0$	0
$\mathcal{P}_{x'}'$	$K_I \sqrt{1 - \epsilon^2} R_{TT'}^{x'0}$
$\mathcal{P}_{y'}'$	0
$\mathcal{P}_{z'}'$	$K_I \sqrt{1 - \epsilon^2} R_{TT'}^{z'0}$

\mathcal{P}_t^0	0
\mathcal{P}_n^0	$K_I(R_T^{y'0} + \epsilon_L R_L^{y'0})$
\mathcal{P}_ℓ^0	0
\mathcal{P}_t'	$-K_I \sqrt{1 - \epsilon^2} R_{TT'}^{x'0}$
\mathcal{P}_n'	0
\mathcal{P}_ℓ'	$-K_I \sqrt{1 - \epsilon^2} R_{TT'}^{z'0}$

\mathcal{P}_x^0	0
\mathcal{P}_y^0	$\frac{1}{2} \sqrt{2\epsilon_L(1 + \epsilon)} K_I(R_{LT}^{x'0} \cos \theta_K^* + R_{LT}^{y'0} + R_{LT}^{z'0} \sin \theta_K^*)$
\mathcal{P}_z^0	0
\mathcal{P}_x'	$\frac{1}{2} \sqrt{2\epsilon_L(1 - \epsilon)} K_I(R_{LT'}^{x'0} \cos \theta_K^* - R_{LT'}^{y'0} + R_{LT'}^{z'0} \sin \theta_K^*)$
\mathcal{P}_y'	0
\mathcal{P}_z'	$\sqrt{1 - \epsilon^2} K_I(-R_{TT'}^{x'0} \sin \theta_K^* + R_{TT'}^{z'0} \cos \theta_K^*)$

$$P_\ell = -P_{z'} \quad P_n = P_{y'} \quad P_t = -P_{x'}$$

$$K_I = \frac{1}{R_T^{00} + \epsilon_L R_L^{00}}$$

ONLY induced polarization part survives for normal components and ONLY transferred part for in-plane components.

Polarization Extraction

Parity non-conservation in weak decay allows to extract recoil polarization from p angular distribution.

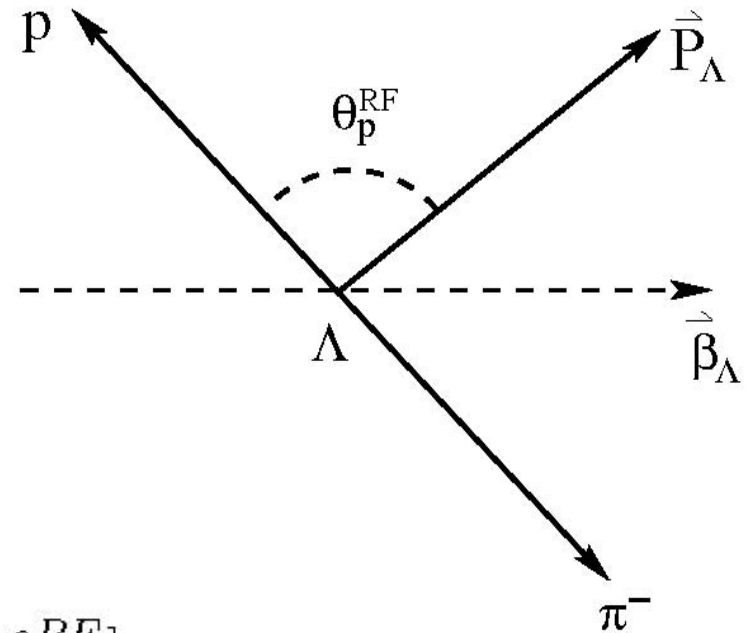
$$\frac{dN}{d \cos \theta_p^{RF}} = N(1 + \alpha P_\Lambda \cos \theta_p^{RF}),$$

$$P_\Lambda = P_\Lambda^0 \pm P_b P'_\Lambda,$$

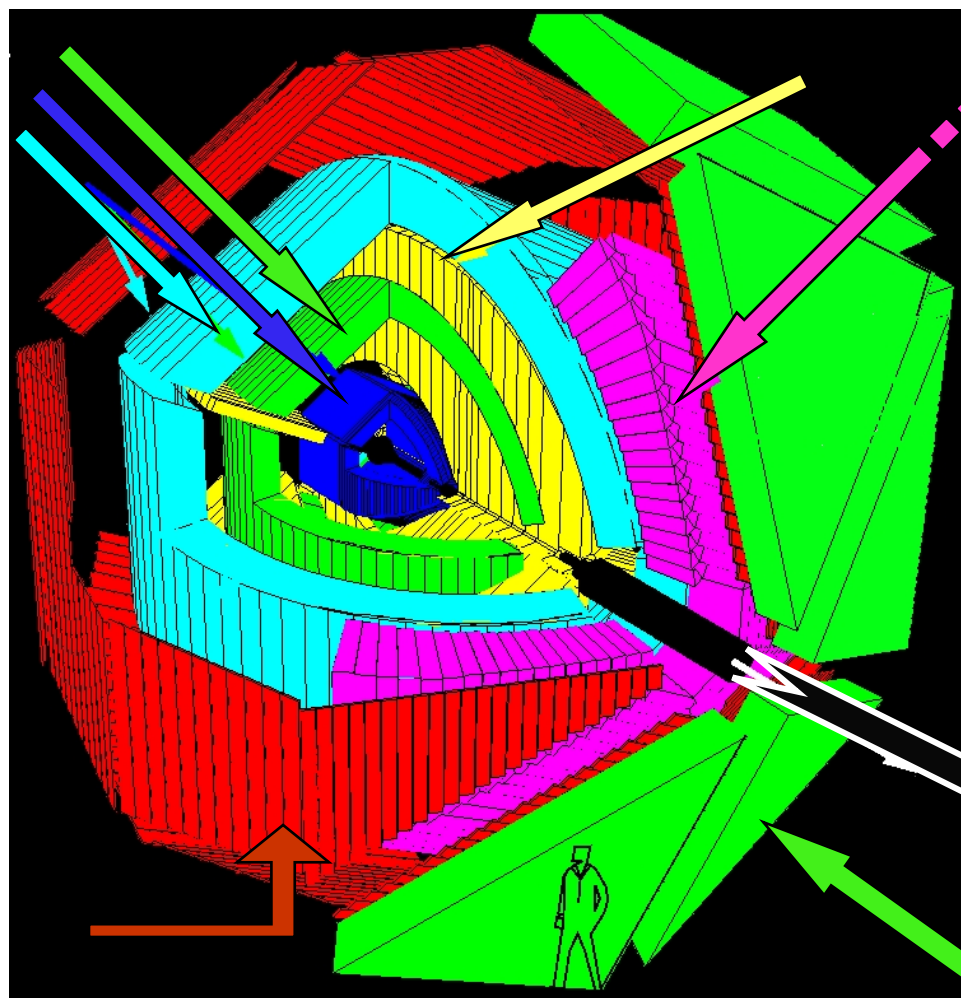
$$\frac{dN^\pm}{d \cos \theta_p^{RF}} = N[1 + \alpha(P_\Lambda^0 \pm P_b P'_\Lambda) \cos \theta_p^{RF}]$$

Where: $\alpha = \frac{2a_s \text{Re}(a_p^*)}{|a_s|^2 + |a_p|^2}$

$$\pi_\Lambda = \pi_{Proton} \pi_{Pion} (-1)^l$$



CEBAF Large Acceptance Spectrometer



- Toroidal magnetic field in region 2

- 3 regions of drift chambers located spherically around target provide charge particle tracking for angle and momentum reconstruction.

- Cherenkov detectors provide e/π separation

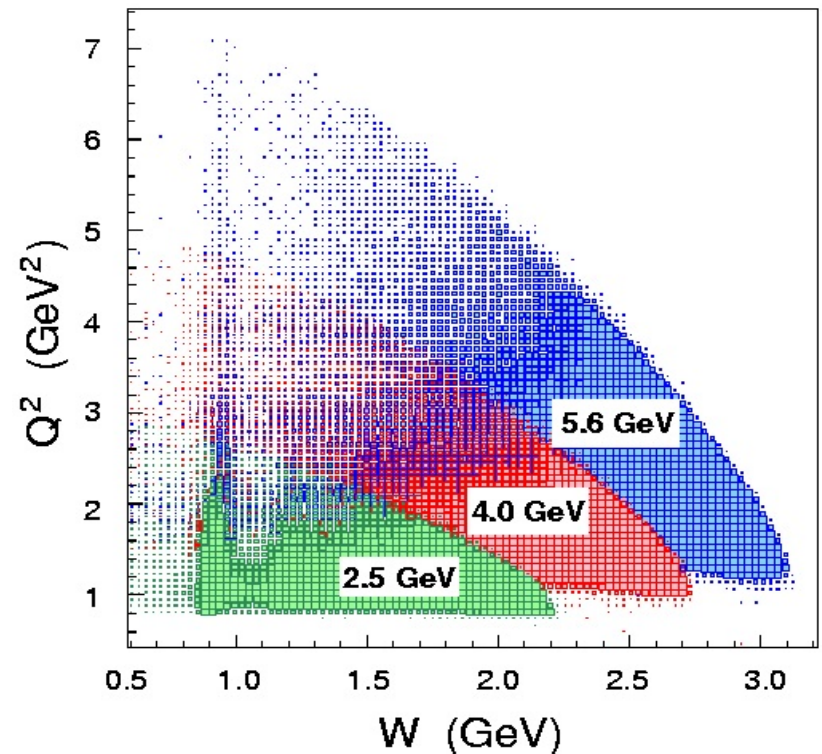
- Electromagnetic calorimeter gives total energy measurement for electrons and neutrals and also e/π separation

beam direction

- Time of flight scintillators $\rightarrow \beta \rightarrow$ particle ID

Experimental Capabilities

- Continuous electron or (tagged) photon beams up to ~ 5.7 GeV.
 - Luminosity up to $\sim 10^{34}/\text{cm}^2/\text{s}$.
 - LH_2 target for most N^* experiments also polarized target capability.
 - Polarized electron beam with $P \approx 85\%$ and polarized photon facility.
 - $8^\circ < \theta < 142^\circ$ ($\sigma_\theta \sim 1$ mrad)
full ϕ ($\sigma_\phi \sim 4$ mrad)
 - $\Delta p/p \sim 1\text{-}2\%$ depending on field setting and particle momentum
 - **Large kinematic acceptance** in Q^2 , W , as well as electron and hadron scattering angles
- Obvious importance in studying kinematic dependencies of cross sections and polarization observables. → access to interference structure functions.



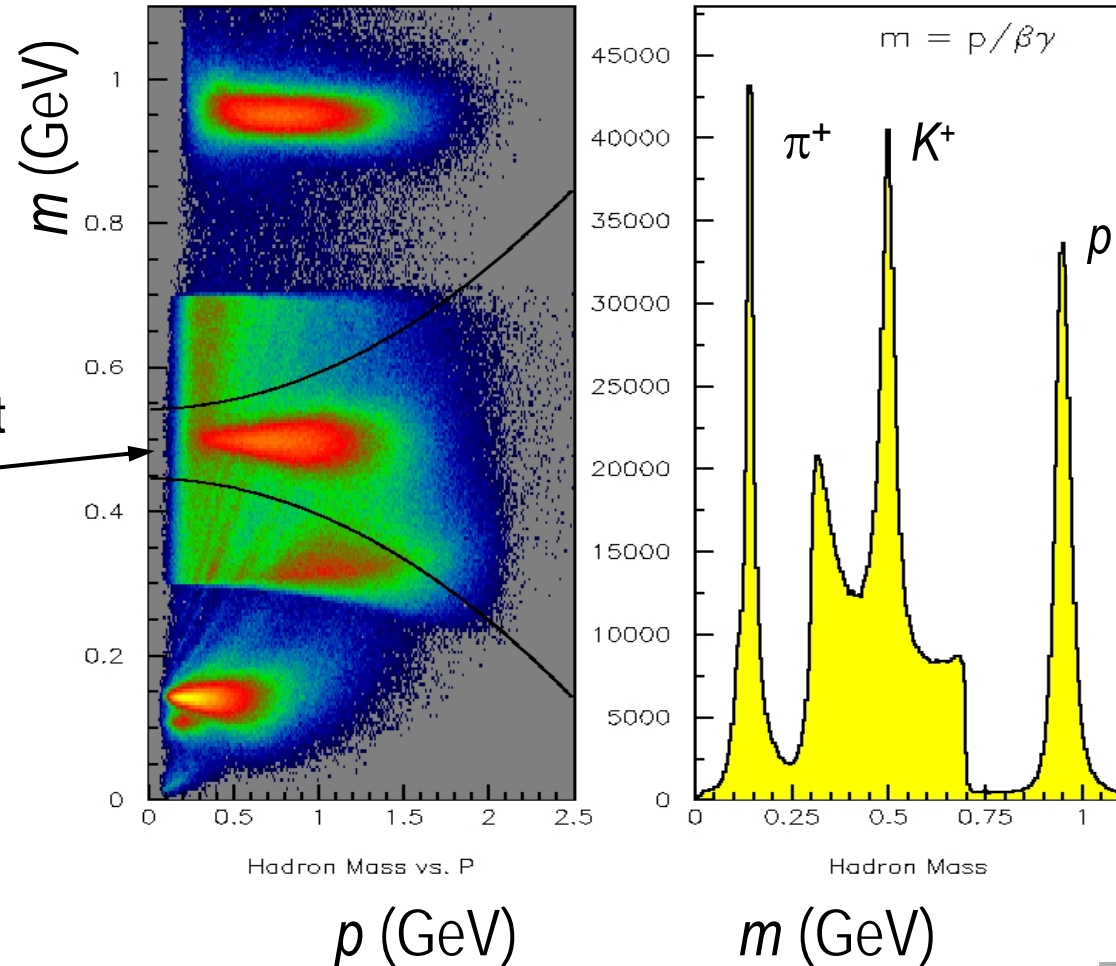
Analysis Method Summary

- Electron identification
 - Good Cerenkov signal
 - Good total energy measurement
 - Good traceback to target
 - Fiducial cuts (flat acceptance region).
 - Momentum corrections (detector misalignments)
- Hadron (K, p) identification
 - Reconstructed mass: $m = \frac{p}{\beta\gamma}$
 - Fiducial cuts
 - Momentum corrections
- Hyperon (Λ, Σ^0) identification
 - Reconstructed missing mass for $e+p \rightarrow e'K^+(\gamma)$
 - For recoil polarization observables $e+p \rightarrow e'K^+p(\pi^-)$ include π^- missing-mass cut.

Hadron Identification

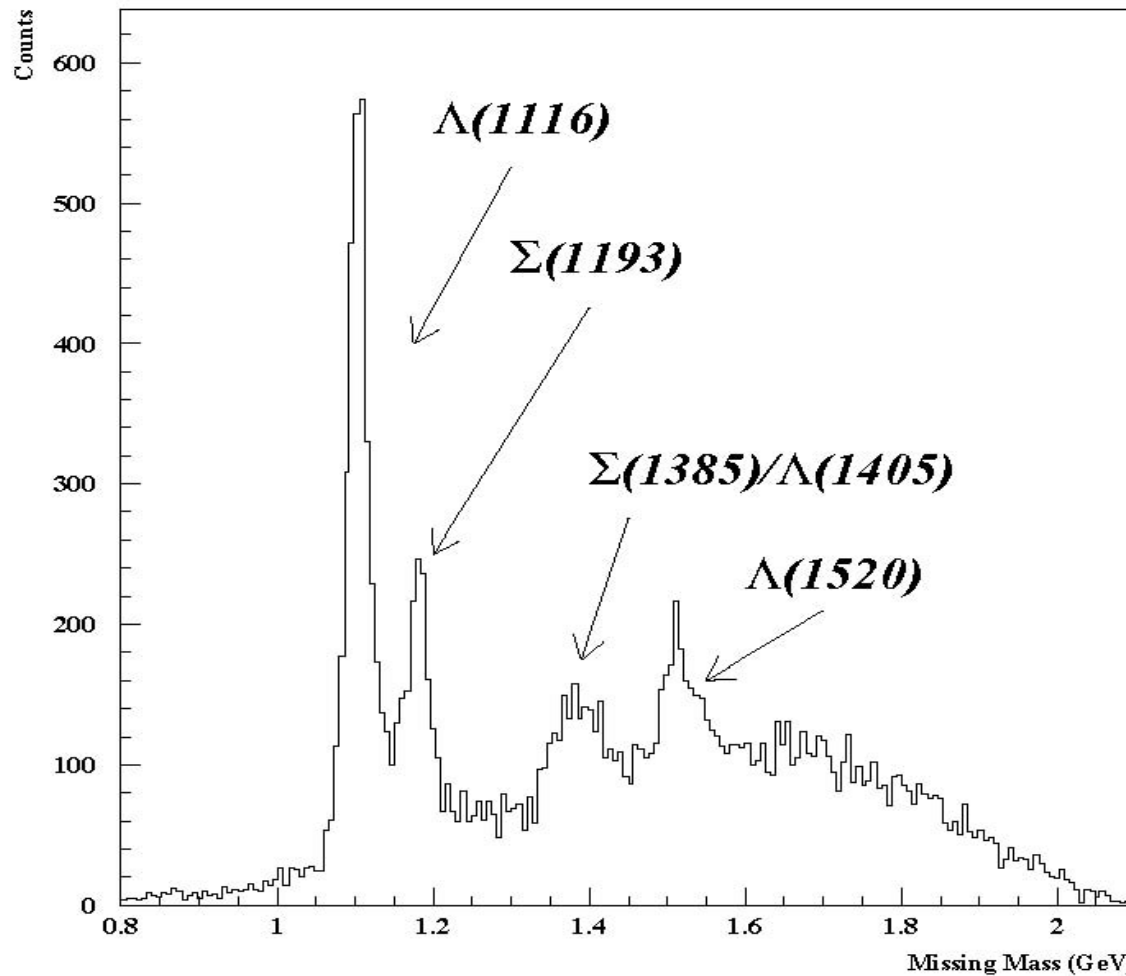
“Skimmed” data:
pre-sorted for
kaon candidates

Momentum-dependent
kaon cut.



Hyperon Identification

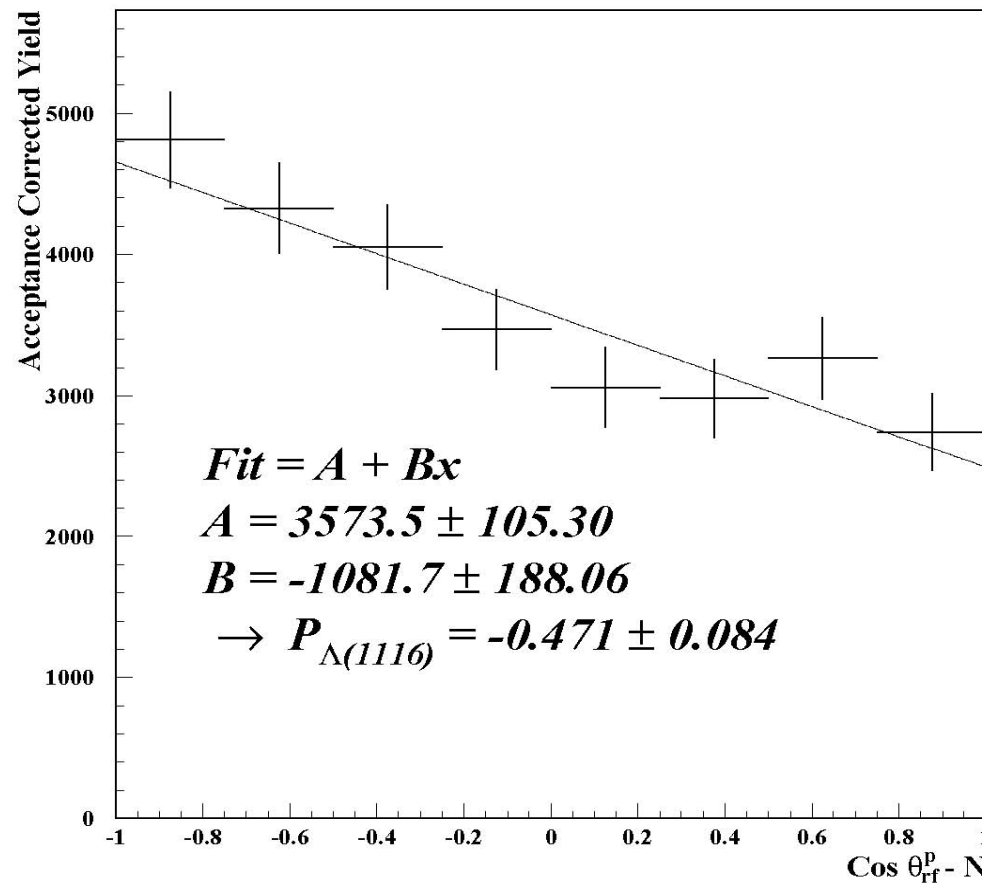
eK missing mass distribution with a proton cut.



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Extraction of Induced Polarization

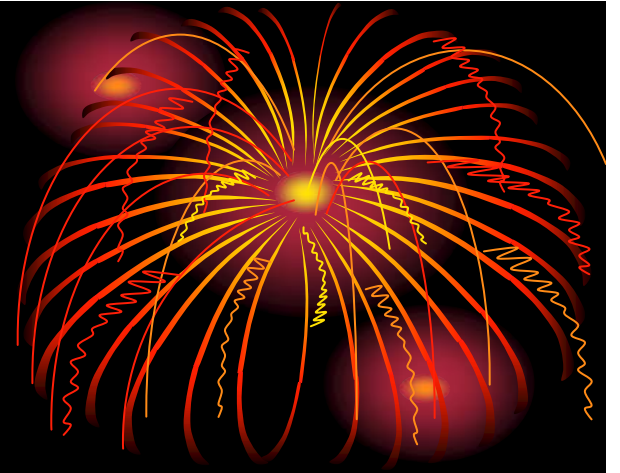
$$\frac{dN^{\pm}}{d \cos \theta_p^{RF}} = N[1 + \alpha(P_{\Lambda}^0 \pm P_b P'_{\Lambda}) \cos \theta_p^{RF}]$$



Summary and Future Work



- *It is necessary to repeat induced polarization measurement. Previous measurement combines data from 4 different data sets with different energies and torus currents.*
- *New electroproduction cross sections resulting in structure function separation for both $K+\Lambda$ & $K+\Sigma$.*
- *Prospects for finding “missing” resonances decaying to strange final states would seem to be good given the wealth of new photo- and electroproduction data.*



THANK YOU !



Quantum Mechanics

S-Wave

$$\psi_s = a_s Y_0^0 \chi^+,$$

P-Wave

$$\psi_p = a_p \left[\sqrt{\frac{2}{3}} Y_1^1 \chi^- - \sqrt{\frac{1}{3}} Y_1^0 \chi^+ \right],$$

$$|J = 1/2, m_z = 1/2\rangle = \psi = \psi_s + \psi_p = \left[a_p \sqrt{\frac{2}{3}} Y_1^1 \right] \chi^- + \left[a_s Y_0^0 - a_p \sqrt{\frac{1}{3}} Y_1^0 \right] \chi^+.$$

$$\psi^* \psi = a_p^2 \left(\sqrt{\frac{2}{3}} Y_1^1 \right)^2 + \left(a_s Y_0^0 - a_p \sqrt{\frac{1}{3}} Y_1^0 \right) \left(a_s Y_0^0 - a_p^* \sqrt{\frac{1}{3}} Y_1^0 \right),$$

$$\psi^* \psi = |a_p|^2 \sin^2 \theta + |a_s|^2 + |a_p|^2 \cos^2 \theta - a_s [a_p + a_p^*] \cos \theta = |a_s|^2 + |a_p|^2 - 2a_s \operatorname{Re}(a_p^*) \cos \theta.$$

$$\alpha = \frac{2a_s \operatorname{Re}(a_p^*)}{|a_s|^2 + |a_p|^2}$$

$$I(\theta) = 1 - \alpha P \cos \theta$$

$$\pi_\Lambda = \pi_{Proton} \pi_{Pion} (-1)^l$$

Pol.		Response Functions								
β	α	T	L	cLT	sLT	cTT	sTT	$^cLT'$	$^sLT'$	TT'
0	0	R_T^{00}	R_L^{00}	R_{LT}^{00}	0	R_{TT}^{00}	0	0	$R_{LT'}^{00}$	0
x'	0	0	0	0	$R_{LT}^{x'0}$	0	$R_{TT}^{x'0}$	$R_{LT'}^{x'0}$	0	$R_{TT'}^{x'0}$
y'	0	$R_T^{y'0}$	\ddagger	\ddagger	0	\ddagger	0	0	\ddagger	0
z'	0	0	0	0	$R_{LT}^{z'0}$	0	$R_{TT}^{z'0}$	$R_{LT'}^{z'0}$	0	$R_{TT'}^{z'0}$
0	x	0	0	0	R_{LT}^{0x}	0	R_{TT}^{0x}	$R_{LT'}^{0x}$	0	$R_{TT'}^{0x}$
0	y	R_T^{0y}	R_L^{0y}	R_{LT}^{0y}	0	\ddagger	0	0	$R_{LT'}^{0y}$	0
0	z	0	0	0	R_{LT}^{0z}	0	R_{TT}^{0z}	$R_{LT'}^{0z}$	0	$R_{TT'}^{0z}$
x'	x	$R_T^{x'x}$	$R_L^{x'x}$	$R_{LT}^{x'x}$	0	\ddagger	0	0	$R_{LT'}^{x'x}$	0
x'	y	0	0	0	\ddagger	0	\ddagger	\ddagger	0	\ddagger
x'	z	$R_T^{x'z}$	$R_L^{x'z}$	\ddagger	0	\ddagger	0	0	\ddagger	0
y'	x	0	0	0	\ddagger	0	\ddagger	\ddagger	0	\ddagger
y'	y	\ddagger	\ddagger	\ddagger	0	\ddagger	0	0	\ddagger	0
y'	z	0	0	0	\ddagger	0	\ddagger	\ddagger	0	\ddagger
z'	x	$R_T^{z'x}$	\ddagger	$R_{LT}^{z'x}$	0	\ddagger	0	0	$R_{LT'}^{z'x}$	0
z'	y	0	0	0	\ddagger	0	\ddagger	\ddagger	0	\ddagger
z'	z	$R_T^{z'z}$	\ddagger	\ddagger	0	\ddagger	0	0	\ddagger	0

Response functions for pseudo-scalar meson production.

G. Knochlein, D. Drechsel, L. Tiator, Z. Phys.A352,327(1995)

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